AD

FUEL REQUIREMENTS FOR LOW-HEAT REJECTION MILITARY DIESEL ENGINES

INTERIM REPORT
TFLRF No. 297

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In the development of high-efficiency advanced engine technology such as low-heat rejection engines and injection systems, the thermal stability of fuel is an important concern. The next generation of engines for combat vehicles will be operating at higher fuel temperatures due to lower waste heat rejection and will be accompanied by higher heat transfer to the fuel injection system. Thus, high-temperature fuel deposit formation is more likely. As a result, two possible methods were evaluated for their potential to reduce fuel deposits: 1) prestress the fuel in an apparatus that feeds the fuel to the engine, or 2) pretreat the fuel with an appropriate additive to reduce deposits in the engine. It was shown that removal of dissolved oxygen from the fuel can significantly reduce the formation of deposits on hot metal surfaces. Prestressing the fuel prior to burning it in the engine was also effective in the reduction of deposit formation. The use of additive pretreatment yielded only limited success.

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EXECUTIVE SUMMARY

Problem: The thermal stability of fuel is an important concern in the development of high-efficiency advanced engine technology. The proposed use of low-heat rejection (LHR) engines makes fuel thermal stability a special consideration for the U.S. military. Increased operating temperatures, combined with heat soakback at shutdown, emphasizes the attention that must be given to the thermal and oxidative stability of fuel. This is especially true when using Grade No. 2 diesel fuel.

Objective: The objective of this project was to evaluate the effectiveness of prestressing and pretreating diesel fuel on the reduction of fuel deposits in a LHR engine heat exchanger and injection systems.

Importance of Project: The means to reduce the formation of fuel deposits in LHR engine heat exchanger and injection systems will allow operation of the engines at much higher temperatures, thereby increasing the efficiency of the engine.

Technical Approach: A referee diesel fuel was subjected to various prestressing and pretreatment schemes. The prestressed/pretreated fuel was then run in an injector fouling bench test and in a prototype single-cylinder LHR engine. Upon conclusion of testing, the injectors were inspected and rated for deposits.

Accomplishments: It was shown that removal of dissolved oxygen from the fuel can significantly reduce the formation of deposits on hot metal surfaces. Prestressing the fuel prior to burning it in the engine proved effective in the reduction of deposit formation as well. However, the use of additive pretreatment yielded only limited success. Based on these evaluations, requirements were proposed for the use of thermally stable fuel in high-temperature fuel injection systems.

Military Impact: The results demonstrate that fuel prestressing and pretreatment can significantly reduce fuel system deposits. Based on the findings of this study, a continued and more in-depth investigation of methods to reduce fuel system deposits in higher temperature engines can be pursued.

FOREWORD/ACKNOWLEDGEMENTS

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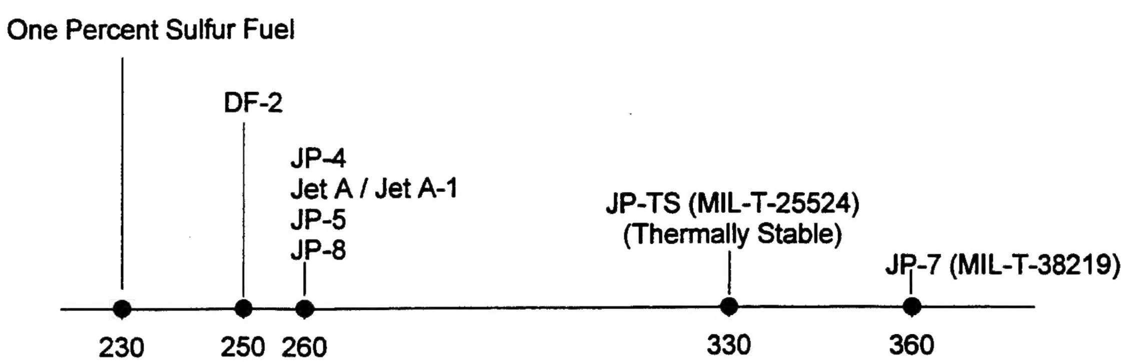
I. INTRODUCTION

In the development of high-efficiency advanced engine technology such as low-heat rejection (LHR) engines and injection systems, the thermal stability of fuel is an important concern. The next generation of engines for combat vehicles will be operating at higher fuel temperatures due to lower waste heat rejection and will be accompanied by higher heat transfer to the fuel injection system. While operating temperatures at the injector tip are expected to reach approximately 200°C, temperatures at the surrounding metal could reach as high as 600°C.(1)* Because of these increased operating temperatures, combined with heat soakback at shutdown, the thermal and oxidative stability of the fuel cannot be ignored. This is especially true when using Grade No. 2 diesel fuel. Aviation turbine fuels currently have a thermal stability requirement at 260°C, which may or may not meet new diesel engine requirements. Typical Jet Fuel Thermal Oxidation Test (JFTOT) breakpoint temperatures are presented for several fuel grades in Fig. 1. Since neither the Army's diesel fuel specification VV-F-800D (2) nor commercial diesel fuels have a thermal stability requirement, injector sticking, heat exchanger fouling problems, and deposit formation are likely to be prevalent in future LHR engines.



(Note: JP-7 test duration was 300 minutes vs. 150 minutes for the other fuels.)

Figure 1. Typical Jet Fuel Thermal Oxidation Test breakpoint temperatures (°C) for several fuel grades

* Underscored numbers in parentheses refer to the list of references at the end of this report.

High-temperature fuel deposit formation is a complex process involving numerous factors. Several mechanisms have been proposed to explain this process. Most researchers agree that deposit formation begins with auto-oxidation of the fuel. The products of oxidation initiate the formation of deposits through additional reactions and various reaction pathways.(3-5) Since dissolved oxygen in the fuel has been shown by several researchers to facilitate the formation of deposits, it follows that removal of dissolved oxygen should reduce the amount of deposit formed at a given temperature. [Separate reviews of the effect of deoxygenation on thermal stability are presented by Taylor (6) and by Hazlett (4).] As the temperature of the fuel increases, deposit formation will proceed through the regime of auto-oxidation and associated reactions until at some temperature, these reactions have essentially ceased. As the temperature continues to increase, other reaction mechanisms will occur. Marteney (7) and Hazlett (8), among others, showed that after the temperature at which oxidation-related reactions cease, deposit formation increases only slightly until the point where pyrolysis reactions begin to occur. This period of reduced deposition rate can be thought of as a transition period between oxidation-related reactions and pyrolysis reactions. Under the conditions of pyrolysis, deposition rates again increase. The temperatures at which these two mechanisms occur (and cease) and the temperature range of the transition phase varies with the composition of the fuel and the level of dissolved oxygen in the fuel. Examples of these transitions and variance in reaction initiation are shown in Fig. 2.

Based on the above information, a method was sought that would reduce injection system deposits in LHR engines. Two possible approaches were considered viable: 1) prestress the fuel in an apparatus that feeds the fuel to the engine, or 2) pretreat the fuel with an appropriate additive to reduce deposits in the engine fuel handling system. Ideally, the prestresser would operate in the temperature range of the transition phase for the fuel. Under this approach, the majority of the deposits would form in the prestresser and not in the engine fuel handling system (i.e., heat exchangers, fuel pump, injectors, metering passages, etc.).

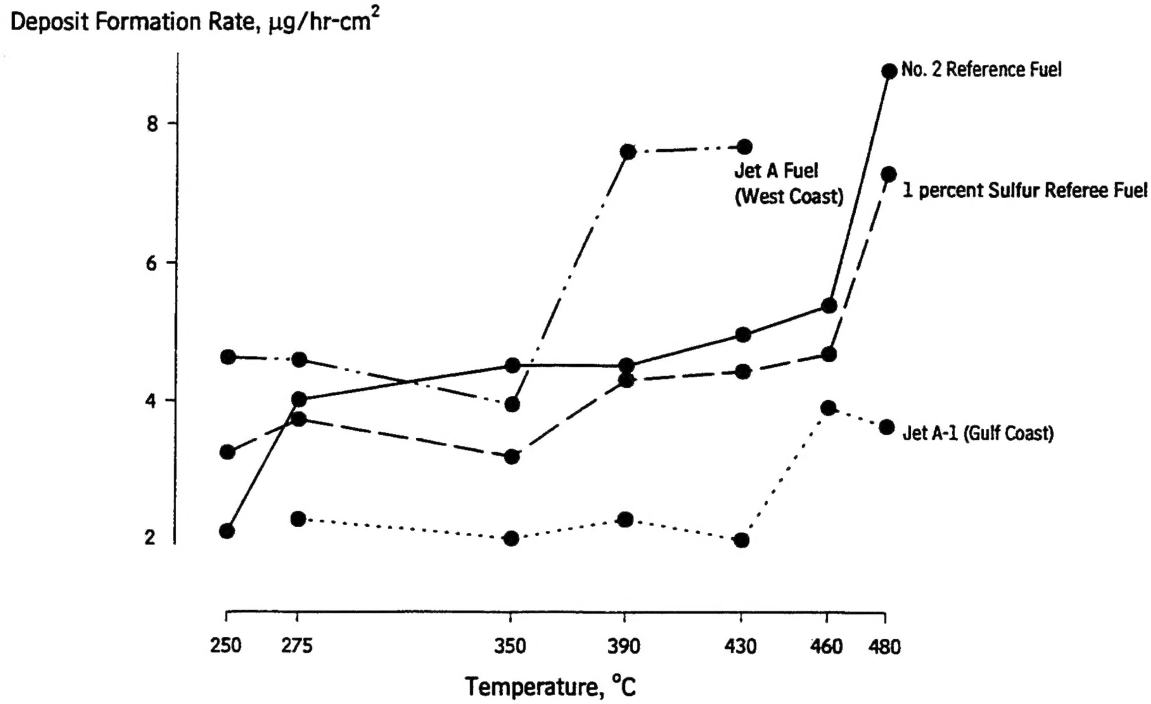


Figure 2. <u>Deposit formation rate vs. temperature for four test fuels</u>

II. OBJECTIVE

The objective of this project was to evaluate the effectiveness of prestressing and pretreatment of diesel fuel on the reduction of fuel deposits in LHR engines. Based on these evaluations, requirements were proposed for the use of thermally stable fuel in high-temperature fuel injection systems.

III. APPROACH

A referee diesel fuel was subjected to various prestressing and pretreatment schemes. The prestressed/pretreated fuel was then run in an injector fouling bench test (IFBT) and in a prototype single-cylinder LHR engine. At the completion of each test, the injectors were removed, inspected, and rated according to the amount of deposit found on the injector and pintle. The amount of deposit formed by the fuel during prestressing was also measured.

IV. EXPERIMENTAL

A. Test Fuel

The test fuel used in this program was a referee grade diesel fuel containing 1% sulfur and meeting the requirements of Military Specification MIL-F-46162C (9), Type I. The fuel was purchased, however, without the mandatory stabilizer additive MIL-S-53021 (10). TABLE 1 presents inspection properties and specification requirements for the test fuel.

Additionally, a Jet A-1 fuel (AL-19554) meeting the requirements of ASTM D 1655 (11) was used in one of the engine tests as a thermally stable baseline fuel. TABLE 2 is a listing of the inspection properties of the Jet A-1 test fuel.

B. Injector Fouling Bench Test

Figure 3 is a schematic of the Detroit Diesel injector fouling bench test apparatus used in this study. (The Appendix contains a copy of the test procedure for the IFBT, and a more complete description of the IFBT can be found in Reference 12.) The IFBT is an 80-hour cyclic test with on-off intervals of 15 minutes each. During the ON cycle, the temperature of the injector tip is maintained at 288°C. The injector tip temperature is not controlled during the OFF cycle. For this reason, the average injector tip temperature tended to vary from test to test.

Three areas on the injector needle--the needle tip, the nonrubbing shaft, and the rubbing area--were rated according to the amount of deposits found in each area. These areas are illustrated in Fig. 4. The method of rating the injector needle deposits utilized the Coordinating Research Council (CRC) brown lacquer merit scale normally used for rating engine deposits. The three areas were also evaluated for deposit thickness and volume using a deposit measuring device (DMD) developed at Southwest Research Institute (SwRI). Additionally, the rubbing and nonrubbing surfaces were rated for deposits using the JFTOT tube deposit rater (TDR).

TABLE 1. Inspection Properties of 1% Sulfur Diesel Test Fuel

Property	MIL-F-46162C Specification Requirements	Test Fuel w/o Stabilizer Additive	Typical MIL-F-46162 Test Results (AL-19409-F)
Density, kg/L, D 1298	Report	0.8698	0.8746
Flash Point, °C, D 93	52, min.	49	73
Cloud Point, °C, D 2500	–13, max.	<–45	–21
Pour Point, °C, D 97	–18, max.	<–45	–36
Kinematic Viscosity, @ 40°C, mm^2/s, D 445	1.9 to 4.1	3.36	3.11
Distillation, °C, D 86			
Initial Boiling Point	Report	180	189
10% Recovered	220, min.	228	220
50% Recovered	255 to 305	274	273
90% Recovered	310 to 360	326	331
End Point	385, max.	372	358
Residue, vol%	3, max.	0.5	1.0
Ash, wt%, D 482	0.02, max.	0.03	<0.01
Carbon Residue, 10% bottoms, wt%, D 524	0.20, max.	0.12	0.15
Particulate Contamination, mg/L, D 2276 modified	10, max.	1.7	5.0
Accelerated Stability, mg/100 mL, D 2274	1.5, max.	1.3	0.1
Total Acid Number, mg KOH/g, D 974	0.2, max.	0.16	0.10
Copper Strip Corrosion, D 130	1, max.	1a	1A
Hydrogen, wt%	NR*	12.96	12.38
Sulfur, wt%	0.95 to 1.05	1.02	1.05
Net Heat of Combustion, MJ/kg (Btu/lb), D 240	Report	42.1 (18119)	42.1 (18119)
Aromatics, vol%, D 1319	Report	33.1	42.0
Cetane Number, D 613	37 to 43	44.5	40.4
Cetane Index, D 976	37 to 43	43.0	41.0
Free Water and Particulate Contamination (visible), D 4176	Pass	Sed/Bright	Pass
Mercaptan Sulfur, wt%, D 3227	NR	0.2086	ND†
Thermal Stability, D 3241			
Filter Pressure Drop, mm Hg, max.	NR	125 in 83.8 min	ND
Tube Deposit	NR	>4P	ND

* NR = Not Required
† ND = Not Determined

TABLE 2. Inspection Properties of Jet A-1 Test Fuel

Property	D 1655 Specification Requirements	Test Fuel
Density @ 15°C, kg/m^3, D 1298	775 to 840	782
Color, D 156	NR*	+25
Distillation Temperature, °C, max., D 86		
10% Recovered	205	167
50% Recovered	Report	175
90% Recovered	Report	195
Final Boiling Point	300	218
Distillation Residue, %, max.	1.5	0.9
Distillation Loss, %, max.	1.5	0.0
Sulfur, mass%, D 4294	0.3	0.002
Freezing Point, °C, max., D 2386	–47	–60
Flash Point, °C, min., D 56	38	44
Viscosity, @ 40°C, mm^2/s, D 445	NR*	1.07
Copper Corrosion, 2 hr @ 100°C, max., D 130	No. 1	1B
Existent Gum, mg/100 mL, max., D 381	7	3.4
Particulates, mg/L, D 2276	NR	0.8
Smoke Point, mm, max., D 1322	25	29
Doctor Test, D 4952	Negative	Negative
Microseparometer, D 3948	Report	99
Hydrocarbon Composition, vol%, D 1319		
Aromatics, max.	20.0	8.1
Olefins, max.	5.0	0.0
Saturates		91.9
Total Acidity, mg KOH/g, max., D 3242	0.1	0.004
Net Heat of Combustion, MJ/kg, min.	42.8	43.5
Thermal Stability, D 3241		
Filter Pressure Drop, mm Hg, max.	25	0.0
Tube Deposit	Code 3, max.	1
Water Reaction, D 1094		
Separation Rating, max.	2.0	0.0
Interface Rating, max.	1B	1A

* NR = Not Required

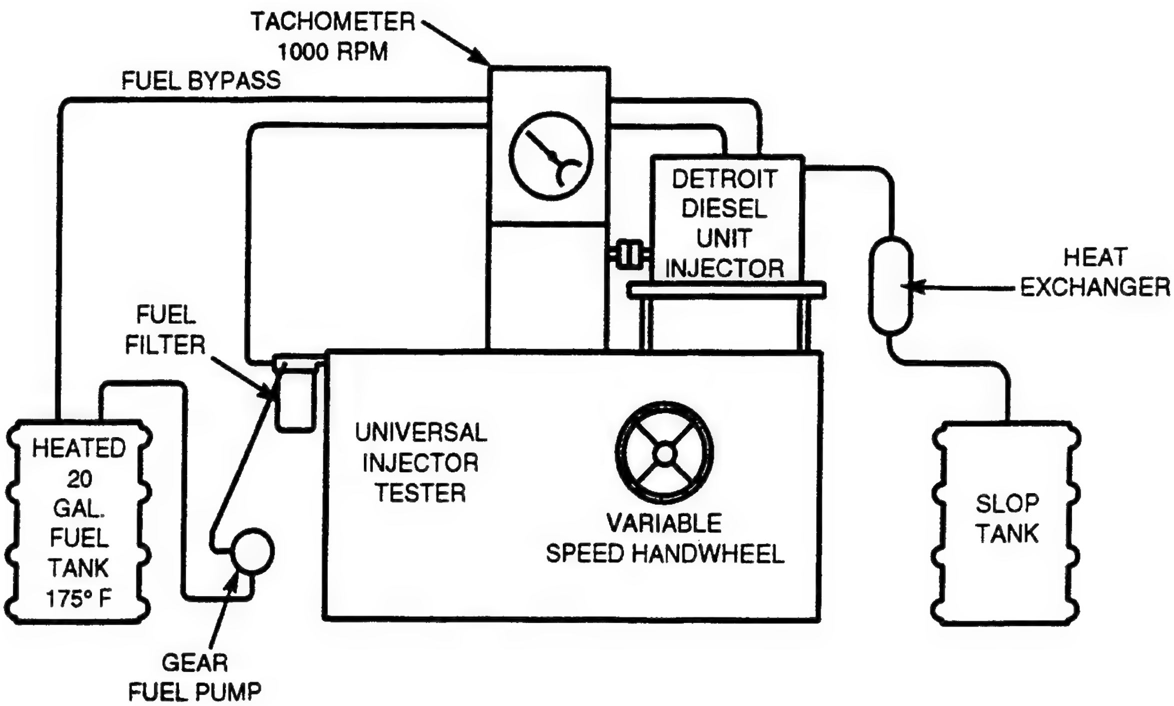


Figure 3. <u>**Detroit Diesel injector fouling bench test apparatus**</u>

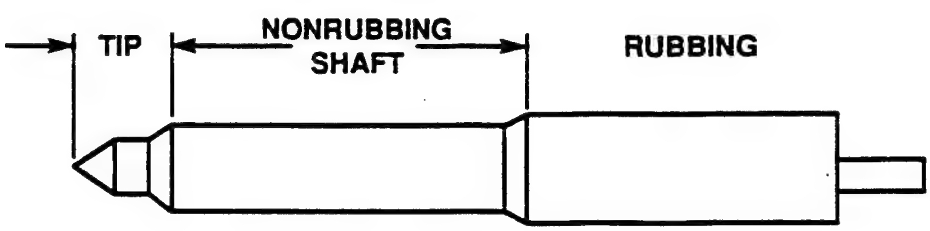


Figure 4. <u>**Areas of injector needle rated for deposits**</u>

C. Experimental Low-Heat Rejection Engine

With the cooling fans and fins removed, a small air-cooled, single-cylinder engine manufactured by Stabilimenti Meccanici VM was used to simulate an experimental, low-heat rejection engine. Heat augmentation and the lack of cooling permitted the VM engine to simulate LHR engine injection system conditions. The engine conditions selected were high heat input and high idle. High idle is a more severe condition as there is little time between cycles for cooling, and the fuel flow rate is very low, minimizing the fuel's ability to cool.

The fuel system was instrumented to record temperatures in the injector body and tip. Injector body temperature was an independent variable. In operating the VM engine at the peak torque condition, a temperature of 304°C was obtained at the injector tip. The cylinder liner was wrapped with insulating material, increasing the tip temperature to 332°C. An insulating washer was then placed between the injector body and cylinder head, and the injector body was wrapped in insulation. This increased the injector tip temperature to 393°C.

The engine was operated for 15 hours at a given load, speed, and injector body temperature. At the conclusion of the test, the injector and needle were rated for deposits. Some discoloration of the needles occurred as a result of metal blueing. Internal fuel leakage from the injector needle was collected and measured.

D. Engine Tests

A total of 12 engine tests were conducted using fuel either prestressed or pretreated in a variety of ways. A MIL-F-46162C 1% sulfur test fuel was used for 11 of the tests, while a clay-treated Jet A-1 fuel was used for engine Test No. 8. The MIL-F-46162C test fuel is normally treated with a stabilizer additive when it comes from the supplier. For the purposes of these engine tests, however, untreated MIL-F-46162C test fuel was used as the baseline fuel. The Jet A-1 was used as a clean fuel comparison since earlier studies with this fuel had resulted in virtually no deposits under these same engine test conditions. Additionally, the 1% sulfur fuel used for the first two tests was procured from a different batch of fuel and contained the MIL-S-53021 fuel

stabilizer additive. These two engine tests were conducted as an evaluation of the engine conditions and modifications and not as a test of fuel prestressing/pretreating. The remaining nine engine tests were conducted using a single 1% sulfur (MIL-F-46162C) test fuel specifically purchased without the stabilizer additive normally present in MIL-F-46162 fuel. For Test Nos. 11 and 12, a stabilizer-type additive was added to the fuel to evaluate the effect. TABLE 3 is a description of the fuel prestressing/pretreating conditions for each of the engine tests.

E. Nozzle Airflow Tester

Nozzle tip spray hole plugging was measured using a nozzle airflow tester. The injector airflow tester is based on International Standards Organization (ISO) 4010-1977 (E) (13). The ISO test apparatus was modified by incorporating a bell jar cover over a metal plate to accommodate CLR-D Bosch (14) and Detroit Diesel injector bodies. A schematic of the modified tester is shown in Fig. 5. A copy of the test procedure can be found in the Appendix.

F. Fuel Prestressing Apparatus

An experimental single tube heat exchanger (STHE) was used to prestress the fuel traveling to the engine. The development of the STHE and the test results collected therefrom are covered in a separate report (15) and resultant paper (16). Figure 6 is a schematic of the STHE. The upper portion of the figure depicts the full STHE, while the lower portion is an enlarged view of the heater and heat exchanger tube. The fuel to be stressed is pumped (using a Rainin Model HPXL, high pressure liquid chromatography solvent pump) through the heat exchanger tube at a preset rate. Prior to engine Test No. 8, the flow rate of fuel through the STHE was set at 10 mL/min. This flow rate was selected to be consistent with the flow rate used in earlier studies of deposit formation mechanisms. A flow rate of 10 mL/min, however, is insufficient to provide fuel directly to the LHR engine. For this reason, the flow rate for engine Test Nos. 9 and 10 was set at 40 mL/min.

TABLE 3. Engine Test Fuel Prestressing and Pretreating Conditions

Test No.	Injector Tip Temperature, °C	Fuel Prestressing/Pretreating Conditions
1	357	1% sulfur plus MIL-S-53021. No prestressing or pretreating. Engine shakedown run.
2	399	1% sulfur plus MIL-S-53021. No prestressing or pretreating. Engine shakedown run.
3	343	1% sulfur without additives. No prestressing or pretreating. Baseline run.
4	343	1% sulfur without additives. No prestressing or pretreating. Nitrogen sparge of the fuel throughout the duration of the test.
5	371	1% sulfur without additives (same as Test No. 4). Recheck results. Nitrogen sparge of the fuel throughout the duration of the test.
6	343	1% sulfur without additives (same as Test No. 4). Recheck results after repair of oil leak in engine. Nitrogen sparge of the fuel throughout the duration of the test.
7	343	1% sulfur without additives. No prestressing or pretreating. Same as Test No. 3. This test was terminated after only 10 hours due to excessive blowby in the engine.
8	316	Jet A-1, clay-treated. No prestressing or pretreating.
9	343	1% sulfur without additives. Fuel flowed through the single tube heat exchanger prior to being burned in the engine but was not heated.
10	371	1% sulfur without additives. Fuel prestressed at 260°C and prefiltered just prior to being burned in the engine.
11	316	1% sulfur treated with MIL-S-53021 fuel stabilizer additive. No prestressing or pretreating of the fuel.
12	Not Recorded	1% sulfur treated with 24 mg/L of fuel antioxidant additive. No prestressing or pretreating of the fuel.

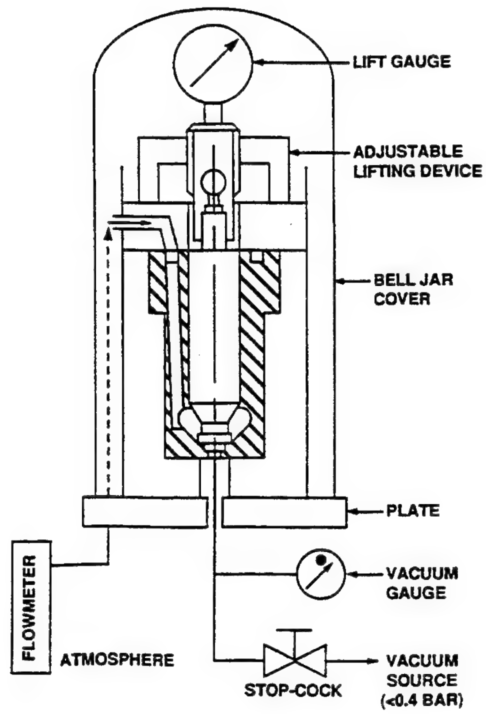


Figure 5. Schematic of modified airflow tester

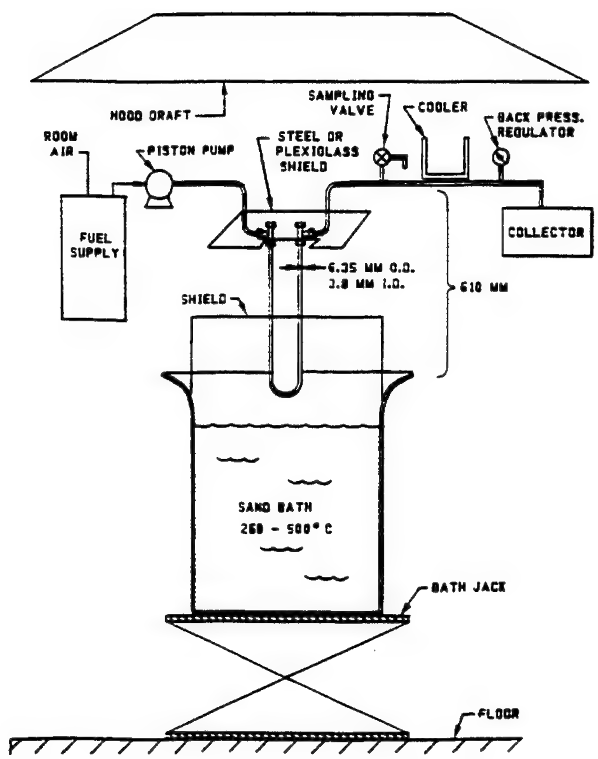


Figure 6. Schematic of single tube heat exchanger

The pressure in the system was controlled by a back-pressure regulator. For this work, the pressure was kept between 5,516 and 6,550 kilopascals (kPa) (800 and 950 psig). The heat exchanger tube was immersed in a fluidized heating bath (Techne Fluidized Bath, Model SBL-2D). The temperature of the bath was adjustable between room temperature and 540°C. The temperature profile inside the u-tube of the STHE was mapped using thermocouples soldered into holes in the wall of the u-tube. Figure 7 is a plot of the temperature profile in the u-tube at each of the set bath temperatures used in this study.

After the fuel passed out of the heat exchanger tube, it flowed through a water-jacketed cooler, through the back-pressure regulator, and out of the STHE. The prestressed fuel was then either collected for analysis or fed to the LHR engine.

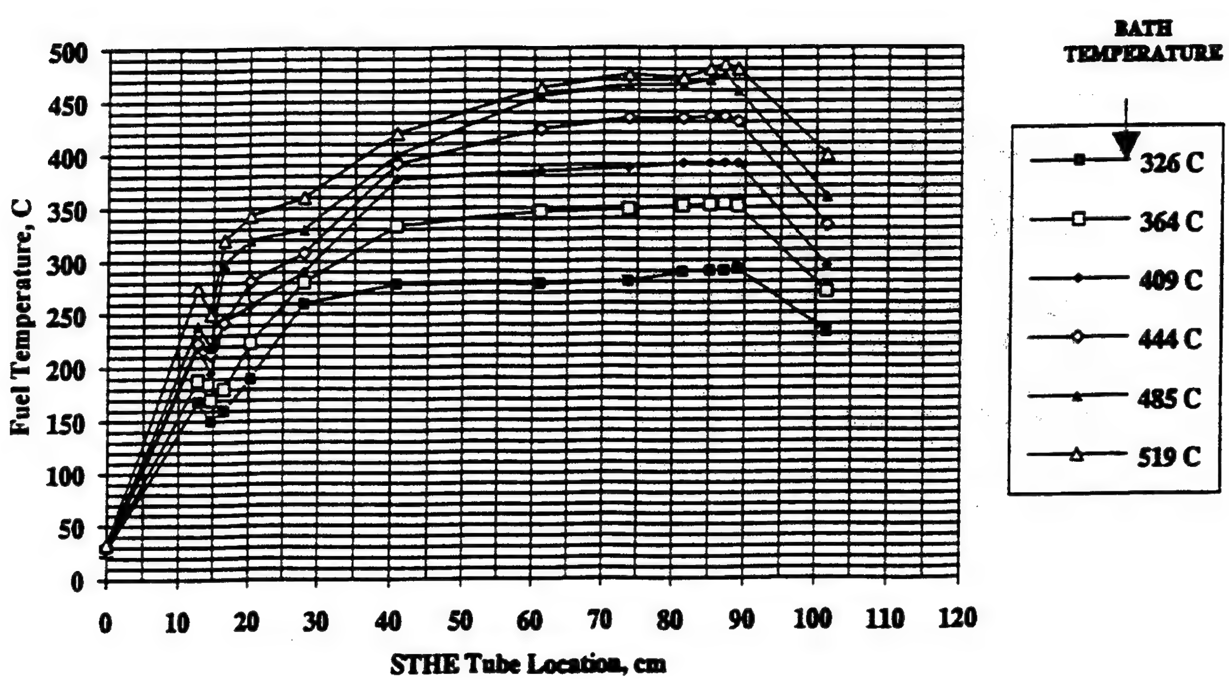


Figure 7. <u>Fuel temperature vs. location in the single tube heat exchanger</u>

G. Pre- and Post-Engine Test Performance Evaluations

In addition to the airflow testing for nozzle plugging, evaluations were conducted of the injection pressure and leakdown time of the injector. In addition, the pintle and plungers were rated for deposits using the CRC lacquer merit scale.

V. RESULTS AND DISCUSSION OF FUEL PRESTRESSING

A. Results of Jet Fuel Thermal Oxidation Test, Injector Fouling Bench Test, and Other Laboratory Testing

A sample of the 1% sulfur fuel was stressed in the STHE at a set bath temperature of 340°C. Samples of the stressed and nonstressed fuels were then subjected to further testing to evaluate any changes in the deposit-forming tendencies of the stressed versus nonstressed fuels. Both stressed and nonstressed fuels were also subjected to testing in the Detroit Diesel IFBT. TABLES 4 and 5 are comparisons of the results of selected laboratory analyses of the stressed and nonstressed 1% sulfur test fuels. TABLE 5 presents the results of testing of the stressed and nonstressed fuels after they had been run through the IFBT. The results show a measurable improvement in the thermal stability characteristics of the stressed fuel as compared to the nonstressed fuel. This is especially evident in the results of the Jet Fuel Thermal Oxidation Test (JFTOT) (ASTM D 3241) (17). The prestressed fuel has a reduced tendency to form deposits on the heated JFTOT tube. The accelerated stability (ASTM D 2274) (18), steam jet gum (ASTM D 381) (19), stability by oxygen overpressure test (ASTM D 5304) (20), and total acid number (ASTM D 3242) (21) results all showed improvement after prestressing the fuel. One potential problem with the prestressed fuel, however, is its increased particulate concentration. The test results indicate that additional vehicle fuel filtration capacity may be required to make prestressing a viable approach.

TABLE 4. Summary of Fuel Analyses Before Injector Fouling Bench Tests

Properties	Fuel Description: AL-19854-F*	Fuel Description: AL-19912-F†
IFBT No.	30-D	31-D
Accelerated Stability, Total Insolubles, mg/100 mL	1.3	0.2
Particulates, mg/L	1.7	28.4
Steam Jet Gum, mg/100 mL	4.8	4.0
Color	1.5	1.5
Oxygen Overpressure, Total Insolubles, mg/100 mL	8.4	1.3
Total Acid Number, mg KOH/g	0.16	0.21
JFTOT Breakpoint Temperature Results Before IFBT		
Test No.	299-T 298-T 297-T	305-T 306-T 307-T
Temperature, °C	215 232 260	215 260 300
Pressure Drop, mm of Hg, in min	0 0 125 in 83.8	125 in 110.2 125 in 118.5 125 in 53.1
Max. TDR, at Station, mm	15 at 46 21 at 44 50+ at 30 to 46	0 0 14 at 36
Visual Rating	3 4P >4P	1 2 4
Max. Thickness, DMD, at Station, µm	<0.050 0.071 at 40 1.771 at 40	<0.050 <0.050 <0.050
Volume of Deposit, DMD, mm^3	<0.0050 0.0082 0.3046	<0.0050 <0.0050 <0.0050
Breakpoint Temperature, Code 3, °C	215	280

* 1 wt% sulfur, without additives

† AL-19854-F stressed at 340°C in STHE

TABLE 5. Summary of Fuel Analyses After Injector Fouling Bench Tests

Properties	Fuel Description: AL-19854-F*	Fuel Description: AL-19912-F†
IFBT No.	30-D	31-D
Test Time, hr	77	80
Accelerated Stability, Total Insolubles, mg/100 mL	2.4	0.2
Particulates, mg/L	2.0	1.5
Steam Jet Gum, mg/100 mL	7.4	4.6
Color	<2.0	1.5
Carbon Residue, mass%	0.13	0.12
Total Acid Number, mg KOH/g	1.79, 0.96	0.18
Visual	Sed/Bright	Sed/Bright
JFTOT Breakpoint Temperature Results After IFBT		
Test No.	301-T‡	304-T§
Temperature, °C♦	215	215★
Pressure Drop, mm of Hg, in min	25 in 150	125 in 105.3
Max. TDR, at Station, mm	9 at 44	0
Visual Rating	3	2
Max. Thickness, DMD, at Station, μm	<0.050	<0.050
Volume of Deposit, DMD, mm^3	<0.005	<0.005

* 1 wt% sulfur, without additives
† AL-19854-F stressed at 340°C in STHE
‡ Prefilter plugged after 90 minutes; removed prefilter to complete test
§ Prefilter plugged after 17 minutes; removed prefilter to complete test
♦ Evaluated at predetermined breakpoint temperature of fuel before IFBT
★ Breakpoint temperature of 280°C was not known when JFTOT was run; used 215°C

TABLE 6 is a summary of the results obtained using the IFBT. IFBT Test 30-D was terminated after 77 hours due to a lack of fuel; an insufficient amount of test fuel was loaded into the fuel container at the beginning of the test. For the purposes of comparison to the prestressed fuel, this 77-hour test was considered complete. The pintle used with the prestressed fuel had lower

pintle merit ratings and a smaller percent airflow loss. The TDR spun deposit rating was also lower for the pintle used with the prestressed fuel.

TABLE 6. Summary of Detroit Diesel Injector Fouling Bench Test Data

Test No.:	Test 30-D	Test 31-D
Fuel Identification:	AL-19854-F	AL-19854-F
Fuel Description:	1% Sulfur	1% Sulfur*
Test Mode/Fuel Volume, gal.	Cyclic/24	Cyclic/24
Nozzle Tip Heating Block, °C	288	288
Test Hours	77†	80
Pintle Merit Rating		
Rubbing	3.00	1.89
Nonrubbing	2.00	8.00
Tip	1.00	1.00
Total (10 = Clean)	6.00	10.89
Airflow, cc/min		
Before	1,240	1,240
After	220	730
% Loss	82	41
TDR Spun Deposit Rating		
Rubbing, max.	53 at 32	23 at 30-31
Nonrubbing, max.	65 at 43-45	59 at 45
Pressure Reference Value		
Before	142	139
After	NR‡	NR
Leakdown ΔP, 15 s		
Before	0	74
After	NR	NR
Fuel Flow, mL/1,000 strokes		
Before (avg. of 3)	98	97
After (avg. of 3)	123	130
Spray Pattern		
Before	Good	Good
After	Bad	Bad

* STHE stressed at 340°C. Reassigned AL-19912-F.
† Ran out of fuel before scheduled 80-hour run.
‡ NR = Not rated. Unable to generate any pressure.

B. Particulates in the Prestressed Fuel

Fuel that has been prestressed in the STHE is generally higher in particulate contamination. As a result, several in-line filters were evaluated on their ability to remove these particles during the STHE run. A candidate filter constructed of silver metal fibers was chosen for further investigation. STHE runs were made with filters of 5.0-micrometer (μm) and 1.2-μm diameter pore size. No significant filter blocking was observed with the 5.0-μm pore size filters in STHE runs at 300, 340, 380, 420, and 460°C set temperatures. The 1.2-μm pore size filters did produce some filter plugging during their STHE runs. Additional testing is necessary to determine the requirements for post-stressing filtration prior to introduction of the fuel into the engine.

C. Low-Heat Rejection Engine Testing

TABLES 7 and 8 present the injector data obtained from the 12 engine tests. The first two tests were run on a high-sulfur fuel with additives as a check of the engine. The first engine test used an REO-203 engine oil. High injector deposits were observed, and the modified ISO airflow procedure showed a 77 percent reduction of the orifice area. The second test maintained the same fuel and test conditions but utilized a low ash oil. Fewer deposits were observed, and the orifice flow revealed only a 28 percent reduction in airflow. The low ash oil was used in the remaining engine tests.

Test results from an earlier, related project showed a reduction of deposits on fuel-wetted hot surfaces when dissolved oxygen is removed from the fuel.(15) Based on these results, engine Test Nos. 3 through 7 used the reference high-sulfur test fuel with and without nitrogen sparging of the fuel during the engine test to evaluate the effect of dissolved oxygen on deposit formation. Test No. 7 was prematurely terminated due to excessive engine blowby. To evaluate the effect of nitrogen sparging, engine Test Nos. 3 and 4 were compared, as well as engine Test Nos. 6 and 7. There is a tendency toward reduced deposits with nitrogen sparging, as measured by the pintle merit rating and the injection pressure. The percent airflow loss results were inconclusive, as were the TDR spun deposit ratings. The result of greatest significance is that the two tests run

TABLE 7. Summary of VM Engine Test Injector Data (Test Nos. 1-6)

Test Number:	VM-1	VM-2	VM-3	VM-4	VM-5	VM-6
Fuel Identification:	AL-19298-F	AL-19298-F	AL-19854-F	AL-19854-F	AL-19854-F	AL-19854-F
Fuel Description:	1% Sulfur	1% Sulfur	1% Sulfur*	1% Sulfur†	1% Sulfur†	1% Sulfur†
Average Injector Tip Temperature, °C	357	399	343	343	371	343
Test Hours	15	15	15	15	15	15
Pintle Merit Rating (10 = Clean)						
Rubbing	6.8	7.5	5.6	7.2	6.1	8.9
Nonrubbing	9.4	1.5	1	1.8	3.4	7.4
Tip	2	1	1	4.5	1	1
Airflow, cc/min						
% Loss	77	28	24	30	33	10
TDR Spun Deposit Rating						
Rubbing, max.	32	32	24	41	34	25
Nonrubbing, max.	42	44	46	50	46	45
Injection Pressure, psi						
Before	3,050	3,000	2,900	2,950	2,975	3,050
After	2,800	2,850	2,900	2,950	3,500	3,050
% Pressure Incr.	0	0	0	0	15	0
Spray Pattern						
Before	Good	Good	Good	Good	Good	Good
After	Good	Good	Good	Good	Good	Good
Holes Plugged	0	0	0.5	0	0	0

* Without additives
† Without additives, with nitrogen

TABLE 8. Summary of VM Engine Test Injector Data (Test Nos. 7-12)

Test Number:	VM-7	VM-8	VM-9*	VM-10*	VM-11	VM-12
Fuel Identification:	AL-19854-F	AL-19554-F	AL-19854-F	AL-19854-F	AL-19854-F	AL-19854-F
Fuel Description:	1% Sulfur†	Jet A-1‡	1% Sulfur§	1% Sulfur♦	1% Sulfur★	1% Sulfur♠
Average Injector Tip Temperature, °C	343	316	343	371	316	316
Test Hours	10▾	15	15	15	15	15
Pintle Merit Rating (10 = Clean)						
Rubbing	8	5.8	6.1	6.8	8.5	7.0
Nonrubbing	4.5	7.5	6.1	5.2	7.1	7.5
Tip	1	3	1	1.0	9.5	2.0
Airflow, cc/min						
% Loss	22	0	64	34	76	38
TDR Spun Deposit Rating						
Rubbing, max.	30	20	34	30	35	36
Nonrubbing, max.	28	41	37	44	34	40
Injection Pressure, psi						
Before	3,050	3,000	3,000	3,000	3,000	3,000
After	3,000	2,850	4,000+	2,950	2,850	2,900
% Pressure Incr.	0	5	25+	0	5	3
Spray Pattern						
Before	Good	Good	Good	Good	Good	Good
After	Good	Good	Poor	Good	Poor	Good
Holes Plugged	2	0	0.5	0	2	0

* Direct fuel flow from STHE into the VM engine
† Without additives
‡ Clay-treated
§ Without additives, no heat
♦ Without additives, STHE heat at 260°C
★ Plus MIL-S-53021
♠ Plus AO-29
▾ Test terminated after 10 hours due to excessive blowby

without nitrogen sparging both resulted in plugged holes, while the two tests run with sparged fuel were devoid of plugged holes. While the results are mixed, they do lead to the theory of a reduction in deposit formation when fuel is sparged with oxygen. Test No. 5 was identical to Test Nos. 4 and 6, though it was run at a higher injector tip temperature. The results of Test No. 5 showed a slight increase in injection pressure.

A clay-treated Jet A-1 fuel was used in Test No. 8 to confirm that the engine test could distinguish a thermally stable fuel.

In Test Nos. 9 and 10, the high-sulfur reference test fuel was pumped through the STHE and then into the engine at a flow rate of approximately 40 mL/min. Test No. 9 used no heat in the STHE prior to pumping the fuel into the engine. The fuel for Test No. 10 was prestressed in the STHE at 260°C set bath temperature. Test No. 10 also had a higher average injector tip temperature than Test No. 9. Test No. 9 had a much greater airflow loss, a higher injection pressure, and increased evidence of hole plugging, as compared to Test No. 10. Comparison of the results of these two tests seems to confirm that thermally prestressing the fuel can reduce the formation of deposits in the hot regions of the engine.

The last two engine tests evaluated additive pretreatment as a means to reduce deposit formation. The 1 wt% sulfur fuel in Test No. 11 was treated with the MIL-S-53021 additive package, while the 1 wt% sulfur fuel in Test No. 12 was treated with a commercially available antioxidant additive. The results of these two tests were compared to those from Test No. 7--a test that used the same test fuel but no additive treatment--as an indication of additive effectiveness; however, Test No. 7 was conducted at a higher temperature than Test Nos. 11 and 12, so the comparison was not direct. In the case of Test No. 11, the additive treatment appears to have had little or no effect on deposit formation in the engine. The results of Test No. 12 show a slight improvement as compared to Test No. 7. Additional testing is required to better document the effects of additive treatment in deposit reduction.

VI. CONCLUSIONS AND RECOMMENDATIONS

- Removal of dissolved oxygen from the fuel can significantly reduce the formation of deposits on hot metal surfaces in the engine. The development of the STHE and the test results collected therefrom were covered in depth in a separate report (15) in which it was recommended that the Army Fuel System Design Guide in The Standard Army Refueling System (22) address reducing the replenishment of oxygen in the fuel as this relates to the design of the tank venting system. Reduction of oxygen in fuel could reduce fuel-insoluble microparticulate, sediment, and harmful deposit formation on hot fuel handling surfaces in current and future engine systems. Quantitation of deposit reduction in adiabatic engine injectors and AGT-1500 turbine nozzles should be evaluated in vehicles with non-breathing fuel systems. Recent work by Jones and Balster (23) has also confirmed the importance of dissolved oxygen content to deposit formation in short-term deposit tests.

- It was demonstrated that deposit formation could also be reduced by prestressing the fuel prior to burning it in the engine. This approach did not seem to be as effective as removal of the dissolved oxygen.

- Additive pretreatment of the fuel yielded only limited success.

- It is recommended that additional LHR engine testing be conducted to evaluate oxygen removal and additive treatment as approaches to reducing fuel system deposits. An online degassing unit, such as those used to degas chromatography solvents, could be evaluated as an engine-mounted apparatus.

- Tests with other additives specifically designed to reduce deposits are needed. The additive package currently used in the U.S. Air Force's JP-8 + 100 fuel described under Amendment No. 1 to MIL-T-83133 would be an excellent candidate.

VII. LIST OF REFERENCES

1. Bryzik, W., et al, "Low Heat Rejection From High Output Ceramic Coated Diesel Engine and Its Impact on Future Design," Society of Automotive Engineers Paper No. 931021, 1993.

2. Federal Specification VV-F-800D, "Fuel Oil, Diesel," Grade DF-2, 27 October 1987.

3. Clark, R.H. and Smith, L., Proceedings of the 3rd International Conference on the Stability and Handling of Liquid Fuels, Institute of Petroleum, London, 1988, pp. 268-282.

4. Hazlett, R.N., *Thermal Oxidation Stability of Aviation Turbine Fuels*, American Society for Testing and Materials, Philadelphia, PA, 1991.

5. Taylor, W.F. and Frankenfeld, J.W., Proceedings of the 2nd International Conference on Long-Term Storage Stabilities of Liquid Fuels, Southwest Research Institute, San Antonio, TX, 1986, pp. 496-511.

6. Taylor, W.F., "CRC Literature Survey on the Thermal Oxidation Stability of Jet Fuels," Report 509, Coordinating Research Council, Atlanta, GA, April 1979, pp. 69-84.

7. Marteney, P.J. and Spadaccini, L.J., *Transactions of the ASME*, Vol. 108, October 1986, pp. 648-653.

8. Hazlett, R.N., Hall, J.M., and Matson, M., *Ind. Eng. Chem., Prod. Res. Dev.*, Vol. 16, No. 2, 1977, pp. 171-177.

9. Proposed Military Specification MIL-F-46162C, "Fuel, Diesel, Referee Grade," 12 November 1985.

10. Military Specification MIL-S-53021, "Stabilizer Additive, Diesel Fuel," 16 February 1983.

11. ASTM Designation: D 1655-94a, "Standard Specification for Aviation Turbine Fuels," American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA, 1994.

12. Stavinoha, L.L., Yost, D.M., and Lestz, S.J., "Diesel Injector Fouling Bench Test Methodology," Interim Report BFLRF No. 267 (AD A254532), prepared by the U.S. Army Belvoir Fuels and Lubricants Research Facility (SwRI), Southwest Research Institute, San Antonio, TX, June 1992.

13. "Road Vehicles – Calibrating Nozzle, Delay Pintle Type," ISO 4010-1977(E), International Organization for Standardization, 1977.

14. Coordinating Lubricants Research Diesel Engine, manufactured by Labeco, Mooresville, IN.

15. Stavinoha, L.L., Westbrook, S.R., and McInnis, L.A., "Mechanism of Deposit Formation on Fuel-Wetted Hot Metal Surfaces," Interim Report BFLRF No. 290 (AD A289847), prepared by the U.S. Army Belvoir Fuels and Lubricants Research Facility (SwRI), Southwest Research Institute, San Antonio, TX, January 1995.

16. Stavinoha, L.L., Westbrook, S.R., and McInnis, L.A., "Mechanism of Deposit Formation on Fuel-Wetted Metal Surfaces," 5th International Conference on Stability and Handling of Liquid Fuels, Rotterdam, the Netherlands, 3-7 October 1994, pp. 211-226, DOE/Conf-941022, April 1995.

17. ASTM Designation: D 3241-94, "Standard Test Method for Thermal Oxidation Stability of Aviation Turbine Fuels (JFTOT Procedure)," American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA, 1994.

18. ASTM Designation: D 2274-94, "Standard Test Method for Oxidation Stability of Distillate Fuel Oil (Accelerated Method)," American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA, 1994.

19. ASTM Designation: D 381-94, "Standard Test Method for Existent Gum in Fuels by Jet Evaporation," American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA, 1994.

20. ASTM Designation: D 5304-94, "Standard Test Method for Assessing Distillate Fuel Storage Stability by Oxygen Overpressure," American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA, 1994.

21. ASTM Designation: D 3242-93, "Standard Test Method for Acidity in Aviation Turbine Fuel," American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA, 1993.

22. Research, Development, and Acquisition Implementation of the Standard Army Refueling System, AMC Regulation No. 70-17, 20 July 1989, DOA, Hdq U.S. Army Materiel Command, 5001 Eisenhauer Avenue, Alexandria, VA 22333.

23. Jones, E.G. and Balster, W.J., "Surface Fouling in Aviation Fuel: Short- vs. Long-Term Isothermal Tests," *Energy & Fuels*, Vol. 9, 1995, pp. 610-615.

APPENDIX

Detroit Diesel N70 Injector Fouling Bench Test (IFBT) Cyclic Procedure

DETROIT DIESEL N70 INJECTOR FOULING BENCH TEST (IFBT) CYCLIC PROCEDURE

1. Preparation for Test

Prior to the test, the injector baseline performance is documented. The injector is examined for injection pressure and leakdown on the Pop-n-Fixture® machine (Attachment A). Additional tests include a nozzle airflow check (Attachment B), fuel flow test (Attachment C), and a TDR spun rating for baseline data of a clean pintle/plunger. This data must be recorded and maintained throughout the test. The test fuel undergoes a battery of tests listed in Table 1.

TABLE 1. FUEL TESTS

Color, ASTM D 1500
JFTOT, ASTM D 3241, Breakpoint
Particulate Contamination, ASTM D 2276
Accelerated Stability, ASTM D 2274
Steam Jet Gum, ASTM D 381
Accelerated Stability, 150°C Test
Carbon Residue, 10% Bottoms, D 524

2. Procedure

Procure 13 gallons of the test fuel. One gallon is sent to the laboratory for testing, and 12 gallons are used for the injector rig test.

The Detroit Diesel Injector Rig controls are listed in Attachment D.

The injector rig is operated in the **automatic cyclic mode,** which automatically turns off the injector rig after 15 minutes. The injector rig remains off for another 15 minutes and then turns back on automatically. This procedure is repeated throughout the test. The injector is operated at the condition described in Table 2.

Record test number of Detroit Diesel N70 Injector Fouling Bench Test in a log book to be kept by the injector rig. Use the letter D after test number to indicate the injector rig used is the Detroit Diesel. Table 3 lists the information to be recorded in the IFBT log book. Figure 1 illustrates the daily log book requirements.

TABLE 2. DETROIT DIESEL N70 IFBT OPERATING CONDITIONS FOR 40 HOURS (8 PER DAY)

	On 15 Minutes	Off 15 Minutes
Speed, rpm	1000	0
Fuel Flow, gal/hr	0.5	0
Fuel Spray Temp, °C (°F)	260 (500)*	Record
Temperature of Nozzle Tip Heating Block, °C (°F)	288 (550)	Record
Fuel Reservoir Temp, °C (°F)	79 (175)	79 (175)

* Target temperature.

TABLE 3. LOG BOOK INFORMATION

Test number

Test fuel by AL-Code

Test fuel description

Date test starts

Date test ends

Total hours of test

First two hours; then approximately each 2 hours for an on-and-off cycle record as follows:

- Ambient temperature
- Humidity
- Test hour
- Speed, rpm
- Time of day
- Barometric pressure
- Wet bulb temperature
- Spray temperature
- Nozzle tip heating block temperature
- Fuel reservoir temperature
- Fuel flow

DETROIT DIESEL N70 INJECTOR FOULING BENCH TEST

Test No.________ Date ________ Technician ________ Page No.________

Test Fuel AL–Code ________

Test Fuel Description ________

Date Test Starts ________ Date Test Ends ________ Total Hours of Test ________

Test Hour								
Time of Day								
Barometric Pressure, in Hg								
Ambient Temperature, Deg. F								
Wet Bulb, Deg. F								
Relative Humidity. %								
Speed, RPM								
Fuel Reservoir Temperature, Deg. F								
Spray Temperature, Deg. F								
Nozzle Tip Heating Block Temperature, Deg. F								
Fuel Flow, mL/MIN (31.5)								

FIGURE 1. DETROIT DIESEL N70 INJECTOR FOULING BENCH TEST LOG SHEET

The fuel lines in the injector rig should be stainless steel, and the fuel reservoir must be made of stainless steel. Copper or brass must not be allowed to come in contact with the test fuel at any time. The reservoir must be clean and able to maintain a fuel temperature of 79°C (175°F) during the daily test and 50°C (122°F) during the time rig is shutdown between daily test runs.

A digital readout thermometer is adequate if personnel are available to check the temperature periodically during the test run.

The injector test is run at maximum temperature for eight hours a day, as listed in Table 4, to enable a 40-hour test to be completed within one week (5 successive workdays). To allow for cool-down time, all heaters, except the fuel reservoir, will be turned off during the last 15 minutes of the eighth hour each day.

At the end of the test, save approximately one gallon of test fuel from the fuel reservoir for further laboratory analyses. Table 5 contains the end-of-test cleanup procedure for the injector rig. The test fuel undergoes a series of tests listed in Table 6.

Post-test performance evaluations include the evaluations of the injection pressure and leakdown time (Attachment A), plus the airflow test for the determination of nozzle hole plugging (Attachment B). The airflow evaluation is a modification of the ISO 4010-1977(E) standard.

Also, following the completion of the test, the pintle/plungers are rated for deposition by the methods listed in Table 7 and compared to their respective before-test measurements. Results are then listed in the work sheets as illustrated in Figure 2. Pintle should always remain wetted by Jet-A except during evaluations (heptane washing is permissible before each evaluation).

TABLE 4. DETROIT DIESEL DAILY OPERATION

1. At 7:30, turn fuel barrel temperature controller up to 175^{o}F.

2. Add any make-up oil (REO 191, AL-6211-L) to rocker arm oiling system and start system dripping slowly.

3. At 8:00 AM, start test; turn on breaker to rig, main power light will come on, turn clock-manual switch to clock and turn nozzle injector controller up to reach test temperature. First 15 minutes of cycle is heat soak.

4. Adjust rpm to 1000.

5. Adjust return pressure to 30 psi.

6. Check fuel flow rate - place graduated cylinder under fuel time valve. Open valve and collect 20 mL fuel. When fuel level reaches 20 mL, mark, start timer and time flow for 1 minute. Close valve. Let collected fuel cool and read volume collected (0.5 gal/hr = 31.5 mL/min). Adjust flow as needed.

7. Fill in the necessary log book information.

8. Check fuel flow rate every hour.

9. Adjust rpm, return pressure, fuel flow, and temperature controllers as required.

10. During the last 15 minutes of run cycle, turn off nozzle controller and turn down fuel barrel controller to 122^{o}F; stop at 8 hours (4:00 PM).

11. Stop recorder, turn off right-side breaker and turn off oilers. Fuel barrel stays on at 122^{o}F overnight.

Note: **At the end of the 40-hour test, a 1-gallon sample of test fuel is taken from the fuel reservoir, properly labeled and taken to chem lab for tests.**

TABLE 5. DETROIT DIESEL INJECTOR RIG END-OF-TEST CLEANUP PROCEDURE

1. When the system has cooled to ambient temperature, remove the fuel filter element and save in a sealed can.
2. Clean filter housing and reinstall without a filter element.
3. Disconnect the fuel lines at the injector and install jumper adaptor to bypass the injector.
4. Disconnect both fuel lines from the lid of the fuel drum and remove the lid. Remove both lines attached to underside of lid and reconnect to pump inlet and return lines. The lid is not used during cleanup. Pump any remaining fuel to waste container.
5. Wash down the inside walls of fuel drum with approximately 1000 mL of iso-octane.
6. Open the drain valve and using electric fuel pump, drain the washings to slop container. Stop pump.
7. Close the drain valve and add approximately 2000 mL of fresh iso-octane to fuel drum.
8. Place the fuel bypass return line in slop can--pump the washings through the system and into waste can. Note: **The return pressure valve might have to be adjusted to get more flow at this point.**
9. Stop the pump and drain the iso-octane from the fuel filter housing.
10. Wash down the inside walls of fuel drum with approximately 1000 mL of TAM.
11. Repeat Step Nos. 6 through 9 using TAM as the wash.
12. Pour approximately 2000 mL of neat Cat 1H or the next test fuel and circulate through the system into waste container to remove any solvents remaining in the system.
13. When the system is pumped dry, install new fuel filter element for the next test.

TABLE 6. AFTER IFBT TEST FUEL ANALYSIS

Color, ASTM D 1500

Visual, ASTM D 4176

JFTOT, ASTM D 3241, Breakpoint Temperature

Particulate Contamination, ASTM D 2276

Steam Jet Gum, ASTM D 381

Total Acid Number, ASTM D 664

Carbon Residue, 10% Bottoms, ASTM D 524

TABLE 7. IFBT DEPOSITION RATING*

Visual CRC lacquer demerit scale

JFTOT visual rating scale

TDR spun rating

Dielectric breakdown by Deposit Measuring Device (DMD)

Stereooptical examination plus micro DMD

* **NOTE:** Prior to testing, rinse the pintle with heptane to remove residual fuel and air dry. After each test, rewet the pintle with Jet-A fuel before replacing in its respective case.

DETROIT DIESEL N70 UNIT INJECTOR
IFBT INSPECTION WORKSHEET

DATE ____________ TEST NO. ____________ TEST HOURS ____________ INSPECTOR ____________

FUEL AL– NO. AND DESCRIPTION ____

TEST	TYP./REF.	BEFORE	AFTER
INJECTION PRESSURE PSI	135		
LEAKDOWN dP;15 SEC.	0		
SPRAY PATTERN	GOOD BAD		
AIR FLOW CC/MIN.	REPORT		
FUEL FLOW ML/100 STROKES	60–75		

PINTLE MERIT RATING		
RUBBING		
AREA	RATE	MERIT
	TOTAL	
NON–RUBBING		
AREA	RATE	MERIT
	TOTAL	
TIP		
AREA	RATE	MERIT
	TOTAL	

STATION	TDR SPUN RATING BEFORE	AFTER	CALC. VALUE

DIELECTRIC BREAKDOWN

STATION	0	90	180	270	AVG.
					CSL

FIGURE 2. DETROIT DIESEL N70 UNIT INJECTOR IFBT INSPECTION WORK SHEET

Attachment A
PART I

Pop-N-Fixture®
J23010
Kent-Moore
Tool Division
29784 Little Mack
Roseville, Michigan 48066

SETUP PROCEDURE

1. Place levers (1) and (2) in rear position.

2. Install proper adaptors and lead injector into position.

3. Open thru-flow valve (over injector fuel fitting).

4. Move valve (3) to clamp position--up.

5. Operate pump lever (4) carefully until injector is clamped.
   Caution: Excessive clamping force will damage the tester.

6. Move valve (3) to test position--down.

SPRAY PATTERN AND TIP TEST

1. Move lever (2) to "spray and tip test position"--forward.

2. Open thru-flow valve.
   Caution: Closed valve will damage left gauge.

3. Operate pump lever (4) and observe spray pattern.

4. Operate pump lever (4) slowly, and observe valve opening pressure reference value (right gauge).

Calibration Fluid (AL-12688-L)
Viscor 1487

Viscosity Oil Co.
2.58 cSt at 100°F
0.823 S.G. at 60°F

Attachment A
PART II

HIGH-PRESSURE TEST

1. Move lever (2) to high pressure--rear position.

2. For crown valve injector, rotate lever (1) to crown valve high-pressure test--forward. For needle valve injector, leave in all other tests--rear.

3. Close thru-flow valve.

4. Operate pump lever (4) slowly until high-pressure gauge reads 1600 to 2000 psi and inspect for leaks.

LEAK DOWN TEST

1. Place levers (1) and (2) in rear position.

2. Open thru-flow valve, close, then pump to 500 psi (approximately).

3. Move valve (3) to clamp position--up.

4. Time pressure drop from 450 to 240 psi (redlines).

UNCLAMPING

1. Open thru-flow valve to release pressure.

2. Move valve (5) to unclamp position--down.

Attachment B

AIRFLOW TESTER PROCEDURE

1. Remove the Bell jar from the tester and lay on its side to keep the rubber gasket clean.

2. Place the "O" ring on the spray assembly and install it in the base of the tester.

3. Attach the adaptor to the pintle stem and tighten the set screw. The adaptor should not prevent the pintle from closing completely.

4. Remove the pintle from the spray assembly.

5. Attach the micrometer to the spray assembly adaptor plate (the circular grooved side of plate faces down) and semitight the nut.

6. Attach the adaptor plate and micrometer to the tester and tighten the screws. The "O" ring on the spray assembly must make a good seal.

7. Swing the micrometer to the side to provide access to the spray assembly. Slide the spring on the pintle and insert pintle into spray assembly. The pintle should move down and spring up freely.

8. While holding pintle in down position, swing the micrometer in place directly over the pintle adaptor and tighten the holding nut on the micrometer.

9. Attach the drive belt and install the Bell jar.

10. Close the inlet valve on the flow meter, have the pintle in the up position and open the vacuum valve. Pull as much vacuum as the system will pull (30 in.) and hold for approximately 10 min. to assure a good seal.

11. Close the vacuum valve and open the intake valve. When pressure returns to zero, close the intake valve.

Attachment B (Cont'd)

12. Put the pintle in the closed position (down) and open the vacuum valve. When the gauge reads 30 in., open the intake valve all the way. There should be no indicated airflow at this point.

13. Slowly raise the pintle using the micrometer in small increments (0.005 to 0.010 in.) and record airflow versus micrometer setting. The maximum airflow is reached when the pintle is all the way up. Convert flow meter reading to cc/min.

14. Close the vacuum valve and open the intake valve. When pressure returns to zero, remove the Bell jar.

Attachment C

FUEL FLOW TESTER FOR DETROIT DIESEL
1000 STROKES

1. Install injector in tester and tighten hand-wheel. Push rack setting on the injector all the way in (wide-open position).

2. Turn on power switch.

3. Reset counter to 1000 strokes and push red start button. When tester stops running after pumping 1000 strokes, empty calibration fluid from graduated cylinder and repeat step 3. This is necessary to purge all air from the system prior to testing injector.

4. Do not reset to 1000! Hold red button in and pump until fluid rises to the zero mL mark on graduated cylinder. Release red button. Reset counter to 1000 strokes and push red start button. When tester stops pumping, record volume collected and empty cylinder.

5. Repeat step No. 4 two times. Three fuel flow tests are required.

6. After third test, empty cylinder and turn power off.

Calibration Fluid used is: AL-12688-L
Viscor 1487

Attachment D

DETROIT DIESEL RIG CONTROLS

1. Power is supplied by two breakers at the rear of test rig. The breaker on the left powers the two wall-mounted temperature controllers. The breaker on the right powers the test rig drive motor and fuel pumps.

2. Temperature Controllers - 2 each for fuel barrel and injector nozzle wall-mounted.

3. Rocker Arm Oiling System - Drip system uses REO-191 (AL-6211-L) filled daily with oil squirt can.

4. Hand Wheel - Used to set rpm (1000 rpm) on electronic tachometer.

5. Micrometer Rack Control - Used to set fuel time at 31.5 mL min. Turn clockwise to increase fuel flow.

6. Fuel Return Valve - Sets return pressure to 30 psi.

7. Red Light is injector power indicator - Red = Power on to system.

8. Timer - Set red pointer to 15 min. cycle on-off timer.

9. Clock + Manual Switch - When in **clock position**, the rig starts and stops automatically (both the fuel pump and the drive motor). When in the **manual position**, the drive motor is started and stopped using start/stop buttons. The pump must be started using pump switch.

10. Fuel Pump Switch - Used to start and stop fuel pump when in the manual mode. Also used to pump solvents during cleanup procedure.

11. Fuel Return Pressure Gauge - This is the only pressure gauge monitored - 30 psi.

12. Fuel Time Valve - Two-way valve for fuel time sampling.

13. Fuel Drain Valve - Located in front of fuel filter housing; used to drain system at E.O.T. and during cleanup procedure.

14. Temperature Controller at Base of Fuel Barrel - Does not need daily adjustment - it stays set at No. 8 for day and night operation - indicator light flashes off and on.

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